Discovery of an Extremely Embedded X-ray Source in the R CrA Cloud Core

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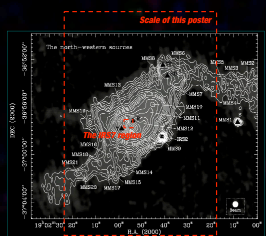
R Corona Australis (R CrA) Star Forming Region

- Nearby ongoing low and intermediate-mass star forming region (*d* ~170 pc)
- IRS7 region: Promising host of Class 0 sources with strong millimeter continuum emission

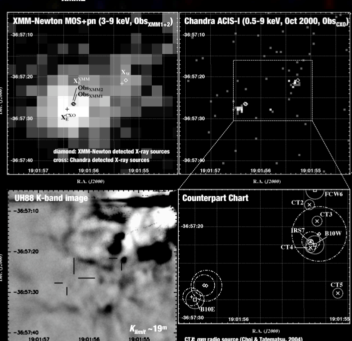


1.2 mm continuum map by Chini et al. (2003)

An Extremely Embedded X-ray Source (X_E^{XMM}) Detected

in two XMM-Newton observations in 2003

- Obs_{XMM1}: March 28 for 36 ksec
- Obs_{XMM2}: March 29 for 32 ksec



CT*X*: *mm* radio source (Choi & Tatematsu, 2004)
B*X*, FCW*X*: *cm* radio source (Brown 1987, Feigelson et al. 1998)
IRS7: near-IR source

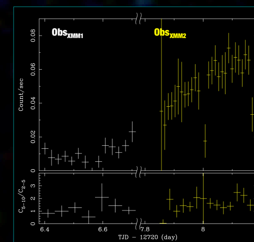
Three sources (X_E^{XMM}, X_E^{CXO} and X_W) were detected in $Obs_{XMM1\&2}$ and the Chandra observation (Obs_{CXO}).

X_E^{XMM} has large N_H and no near-IR counterpart
➔ Class 0 protostar or intermediate phase between Class 0 and Class I protostars

No X-ray detection of X_E^{XMM} in Obs_{CXO}
➔The L_X in $Obs_{XMM1\&2}$ increased more than 30 times compared with Obs_{CXO}.

X-ray Property of X_E^{XMM}

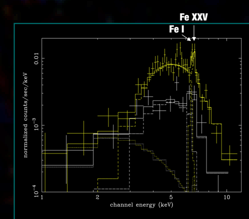
(Yellow colors are of Obs_{XMM2})



Light Curve *(2ks bins for Obs_{XMM1}, 1ks bins for Obs_{XMM2})*

- Gradual flux increase in Obs_{XMM2}
- No significant change in the hardness ratio

➔No prominent heat up of plasma



Spectra *(Fit assumes absorbed 2T plasma w/ a Gaussian at 6.4 keV for Fe I)*

Strong absorption below 3 keV
➔N_H~ 2.8 x10^{23} cm^{-2} (equivalent to Av ~180^m)
Hard band continuum and He-like Fe line
➔ Hot plasma, kT ~2.7, 4 keV
Large X-ray luminosity
➔ Log Lx ~ 30.8, 31.2 ergs s^{-1}
Fe I line is reflection of the incident X-rays by ambient gas
➔ large EW ~810, 250 eV

Caption of the Background Image

X-ray true color image of the R CrA region combined of Obs_{XMM1} and Obs_{XMM2}. Image is color coded to represent hard band (3-9 keV) to blue, medium band (1-3 keV) to green and soft band (0.2-1 keV) to red. Abbreviations in source names - HAeBe: Herbig Ae/Be stars, (W)TTS: (Weak-lined) T-Tauri star, Class I: Class I protostar

Introduction to X-ray Activity of Young Stars

Earlier observations suggest:

- Low mass pre-main-sequence stars (T-Tauri stars, Class I protostars) have strong X-ray emission.
- The high energy activity would be produced by magnetic activity on or around proto-stellar cores.
- X-ray plasma is hotter in the earlier Class I protostar phase than in the T-Tauri phase (Imanishi et al. 2001).

X-ray emission from the earliest phase of protostars (dynamical accretion phase, so called Class 0)

- was tentatively detected in the OMC-3 and Trifid nebula (Tsuboi et al. 2001, Rho et al. 2004).
- has N_H ~ 4-30 x10^{22} cm^{-2} and Lx ~ 10$^{30-31}$ ergs s^{-1} though their photon statistics is quite limited (~50 photons for each source) and thus the derived values have large uncertainty.
- had never been detected from other Class 0 protostar candidates (Montmerle 2003). Moreover, one in the OMC-3 might be produced by collision of outflows from a nearby Class I protostar with interstellar matter (Tsujimoto et al. 2004). X-ray activity of bona-fide Class 0 protostars is not understood yet.

References

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How are these X-ray properties explained?

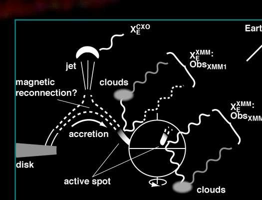
X-ray activity enhanced in $Obs_{XMM1\&2}$
➔ X-ray activity might be triggered by FU Ori type mass accretion outburst (Kastner et al. 2004).

Slow X-ray flux increase in Obs_{XMM2}
➔ The event would not be made by a magnetically generated X-ray flare
Large EWs of the Fe I fluorescent lines
➔ Direct X-ray emission should be partially covered (Inoue 1985).
– Obs_{XMM1}: 60% Coverage ‣ Intrinsic log L_X ~ 31.2 ergs s^{-1}
➔Intrinsic X-ray emission would not change between $Obs_{XMM1\&2}$.
➔Apparent time variation might be produced by proto-stellar core rotation with a period >2.8 days.

The intrinsic L_X unchanged during $Obs_{XMM1\&2}$.
➔X_E^{XMM} was in a quiescent phase in $Obs_{XMM1\&2}$
➔The quiescent X-ray activity (kT, L_X) far exceeds the typical of Class I protostars, and comparable to X-ray flares from Class I protostars.

X_E^{CXO} has
- moderate X-ray absorption (N_H ~4e22 cm^{-2})
- a VLA radio counterpart but no near-IR counterpart

➔ might be shock heated plasma by a collision of a jet emanating from X_E^{XMM}



Possible geometry of the system